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Boulder Laboratories

ANALYSIS OF IONOSPHERIC VERTICAL SOUNDINGS FOR ELECTRON DENSITY PROFILE DATA

III. PROCEDURES FOR OBTAINING MONTHLY SUMMARY VIRTUAL HEIGHT CURVES FOR N(h) ANALYSIS (COMPOSITE VIRTUAL HEIGHT CURVES)

BY J. W. WRIGHT

U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS

Technical Note

146

May 1, 1962

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Abstract

Procedures are described for use at ionospheric sounding stations for obtaining a median virtual height curve from a number of individual ionospheric vertical soundings. This median curve may then be analyzed to find an electron density profile representative of the individual observations. The method is advocated as an economical way to obtain a world N(h) morphology and to obtain control data for studies using more detailed and accurate profiles.

Foreword

This series of reports concerns methods in use or available at the National Bureau of Standards for analysis of ionospheric vertical soundings to obtain electron density profile data. Previous reports have described overlays for convenient manual analysis of ionograms (Wright and Norton, 1959), and for extrapolation of N(h) profiles above hmax F2 (Wright, 1959). The present report describes a procedure for obtaining a median virtual height curve from a superposition of many curves, from which an N(h) profile representative of the constituent observations can be calculated. The basic concept described here was first suggested by Schmerling and Thomas (1956), was more fully described by King (1960), and was tested in comparison with other methods by Wright (1960).

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1. Introduction

As techniques continue to be developed for obtaining electron density profiles from ionograms, it is becoming clear that several different kinds of such data may usefully be obtained from the same ionograms. On the one hand, individual ionograms or groups of ionograms may be analyzed to obtain individual electron density profiles for special studies; usually great detail and accuracy is desirable in such studies, requiring corresponding care and precision in preparation of the "input" virtual height data. On the other hand, a great need exists for a broad survey of the average height structure of the ionosphere, in all its geographic, diurnal, seasonal and solar variations. It is clear that such average profiles (for example, averages of all the quiet days in a month at a particular hour) will not show all the fine detail of an accurate individual profile, since these fine details may not be consistently present on each virtual height curve. Consequently, for the purposes of obtaining average profiles it is not necessary to employ scaling or calculation methods which require extremely great care and precision in preparing the input data.

Until recently, the accuracy of calculated electron density profiles was limited by the mathematical techniques available, provided reasonable care had been exercised in scaling the ionograms. In fact, even with the best ionograms, there was little hope of obtaining

much more detail on an individual profile than in a month's average. However, there has been great progress recently in the development of techniques; methods are now available which can give highly detailed and accurate N(h) profiles, provided the ionograms are of excellent quality, and provided they are very carefully and meticulously scaled. Such scaling is very laborious and is not well suited to routine calculation of large numbers of profiles. The older, rather crude methods are still suitable for obtaining average profiles, and it therefore becomes desirable to employ an ionogram scaling method of appropriate simplicity. Obviously, if the virtual height curves may be averaged together in a simple way, much labor in scaling and computing from the individual curves may be saved.

This note describes an efficient process for obtaining and scaling an "average" virtual height curve. The process has been tested at a small number of ionosphere stations for two years, and has been shown to be a very convenient way of obtaining median N(h) profiles which correspond with acceptable accuracy to the "mean-quiet profile" obtainable by averaging individual profiles (Wright, 1960). The method was recommended for international systematic use by the URSI World-Wide Soundings Committee at its 1961 meeting in Nice.

II. Basic Principle

Each of the ordinary-ray virtual height curves over which the average is to be taken is traced onto the same sheet of standard "Ionogram Tracing" paper. A "median virtual height curve" is obtained by a simple counting process. This median curve is then scaled for the numerical values of virtual heights required for calculation of the median electron density profile. An example of the composite virtual height curves, obtained in a month's scaling at 2100 hours local time, is shown in figure 1.

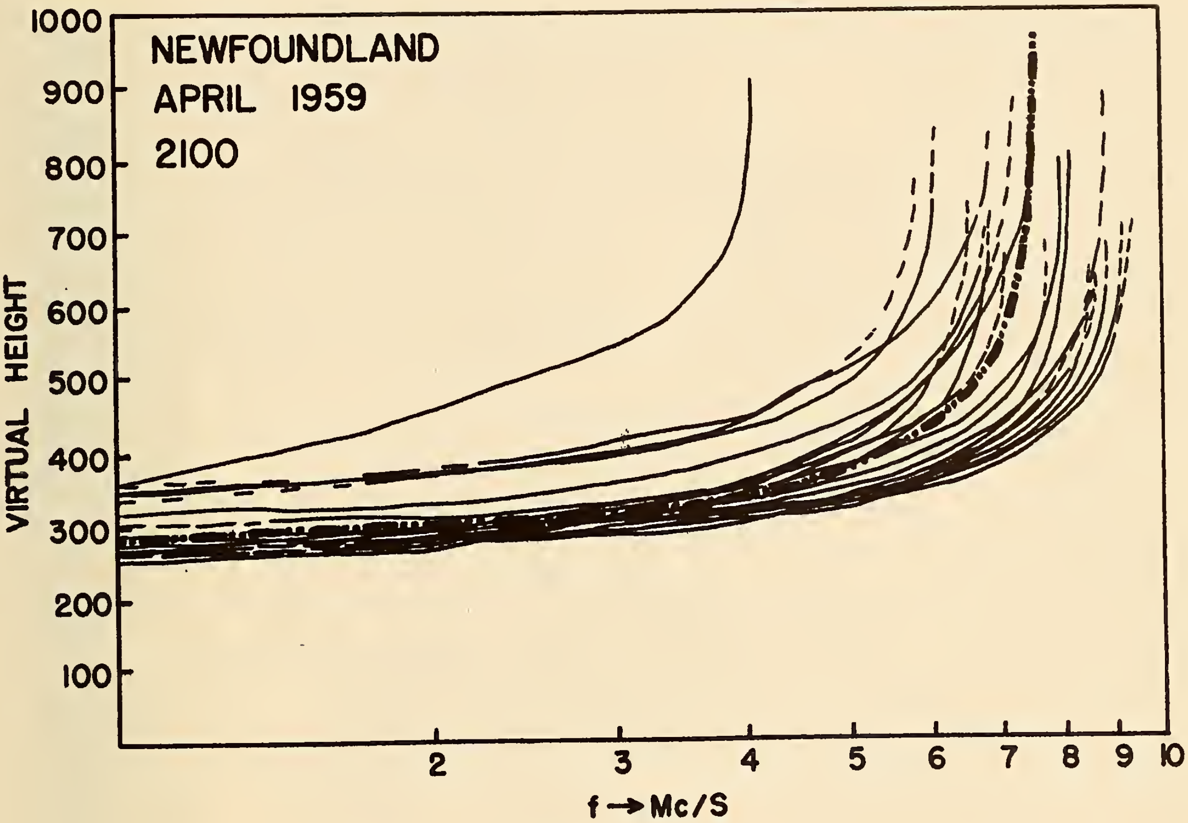


Figure 1

III. Recommended Program; Facilities Needed

The standard program recommended by the URSI/WWSC calls for determination of monthly median virtual height curves at hourly intervals. Thus, in the course of a month's operation, twenty-four sheets (one for each hour) of standard Ionogram Tracing paper would accumulate tracings of the entire month's hourly virtual height curves. These tracings are most easily made by using a "front projection" type scaling table (fig. 2) which can project the ionogram onto the "Ionogram Tracing" form with proper optical magnification to fit the height/frequency coordinates of the form. A copy of the form currently in use for C-model ionosondes is shown in figure 3. The single curve is intended to illustrate numerical scaling methods, and will be discussed in Section X.

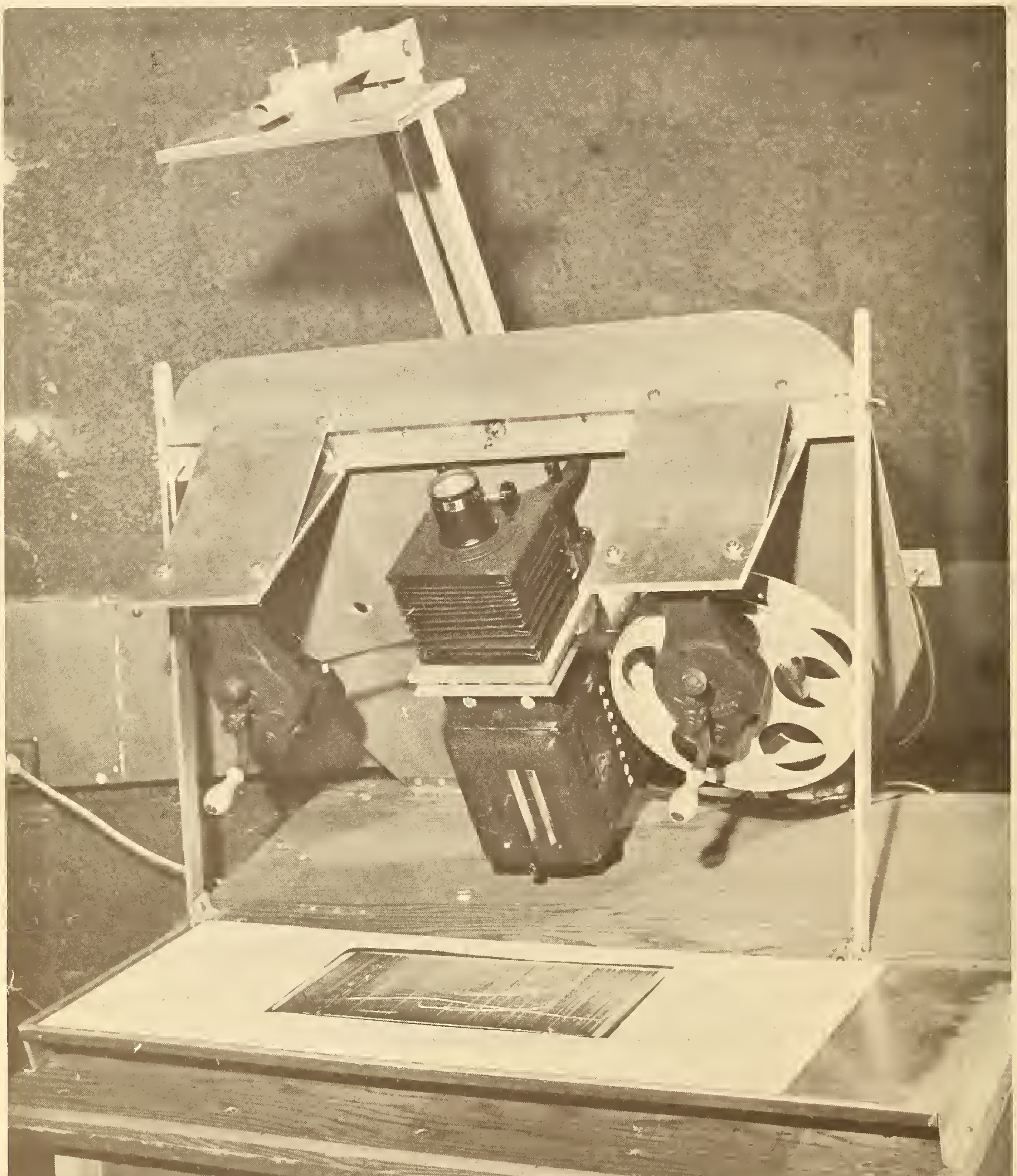


Figure 2

ca

B

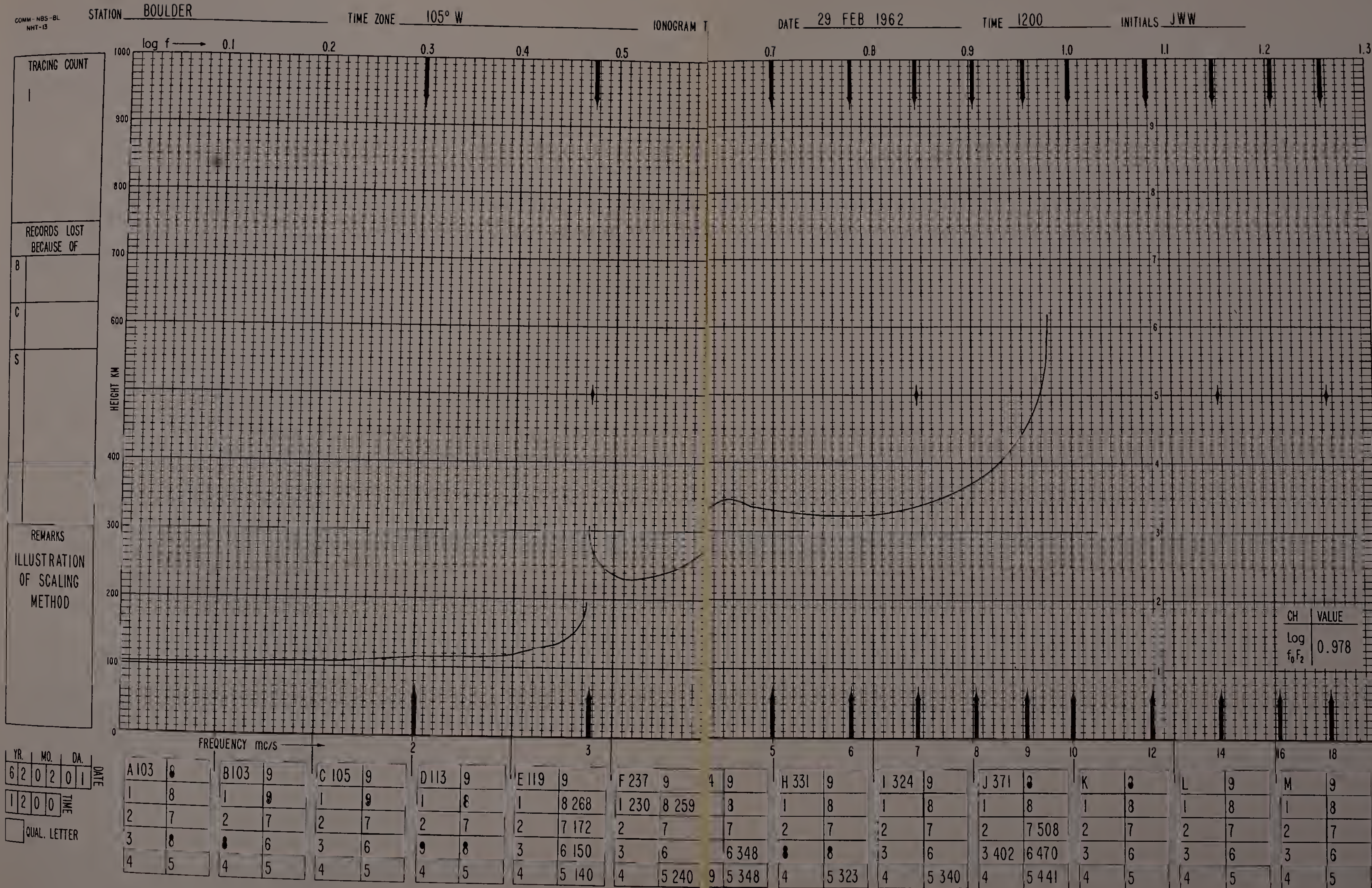
C

S

1

6

1



COMM-NBS-BL NHT-13
STATION BOULDER
TIME ZONE 105° W
IONOGRAM T
DATE 29 FEB 1962
TIME 1200
INITIALS JWW
TRACING COUNT
1
RECORDS LOST BECAUSE OF
B
C
S
REMARKS
ILLUSTRATION OF SCALING METHOD
log f
0.1
0.2
0.3
0.4
0.5
0.7
0.8
0.9
1.0
1.1
1.2
1.3
HEIGHT KM
1000
900
800
700
600
400
300
200
100
0
FREQUENCY mc/s
2
3
5
6
7
8
9
10
12
14
16
18
CH
VALUE
Log f_oF_2
0.978
YR. MO. DA.
6 2 0 2 0 1
DATE
1 2 0 0
TIME
QUAL. LETTER
A 103
B 103
C 105
D 113
E 119
8 268
7 172
6 150
5 140
F 237
1 230
8 259
5 240
6 348
5 348
H 331
5 323
I 324
5 340
J 371
7 508
3 402
6 470
5 441
K
L
M

Figure

It is strongly urged that scalers trace the various curves onto the form lightly with a sharp, hard pencil. When 30 curves have been accumulated on the form, the advantages of this will be apparent. Special pencils, with replaceable leads, erasers, and sharpeners are available to NBS and associated stations as "Ionogram Tracing Pencils."

IV. Precautions: Ionogram Scales

It is absolutely essential that the ionosonde be adjusted so that the ionogram height and frequency markers fit the scaling form exactly. This should be carefully and critically checked at least once per day, and the ionosonde adjusted accordingly. The procedure for this adjustment on C-model ionosondes is as follows:

a) The scaling table should first be adjusted, without film, so that the light strikes the scaling surface perpendicularly at the center of the projected area. This may be easily checked by viewing the shadow cast by a right-triangle held on edge against the center of the scaling surface.

b) It is assumed that the VFO and camera motors run at their nominal (marked) speeds and that the correct gear positions are used. If there is any doubt regarding motor speeds, they should be checked against an accurate clock. Defective motors should be replaced.

c) Without regard to the height markers, the scaling table magnification should be adjusted so that the frequency markers of an ionogram exactly fit the frequency scale of the tracing form. Note that the beginning and end of the ionogram also effectively represent frequency markers.

When the scaling table has received these adjustments, it should never be necessary to change them again. All further adjustments should be done on the ionosonde. Note: If alignment of all of the frequency markers cannot be achieved whatever the adjustment of the scaling table, then the VFO cam and/or trimmers are not correctly adjusted, and the markers (observed with earphones) will not occur at their proper places on the frequency dial. See the ionosonde manual for the proper alignment procedure. Before deciding to re-cut the VFO cam, please inform the Equipment Development Group, NBS.

d) When alignment of the frequency markers with the standard form is satisfactory, examine the height markers and determine whether they are expanded or compressed. Judge the amount of expansion or compression, in percent, by counting ionogram markers vs. height lines on the form. Adjust the height scale expansion control of the ionosonde to achieve the proper expansion or compression of the markers. If necessary, make several test ionograms around the approximate position, and mark the control for each one. Compare the ionograms, in the scaling table, with the standard form, and adjust the ionosonde again if necessary. If the height markers are non-linear, adjust the linearity control for best linearity.

Do not be satisfied with poor height marker alignment! It is very important to your own scaling and to those who use the ionograms later that the markers fit the standard form exactly. If you find difficulties you cannot deal with alone, ask the Equipment Development Group at NBS for assistance.

V. Obtaining the Median Virtual Height Curve

There is a unique median virtual height curve defined by the composite virtual height curves. This is easy to see in the simplified diagram of figure 4:

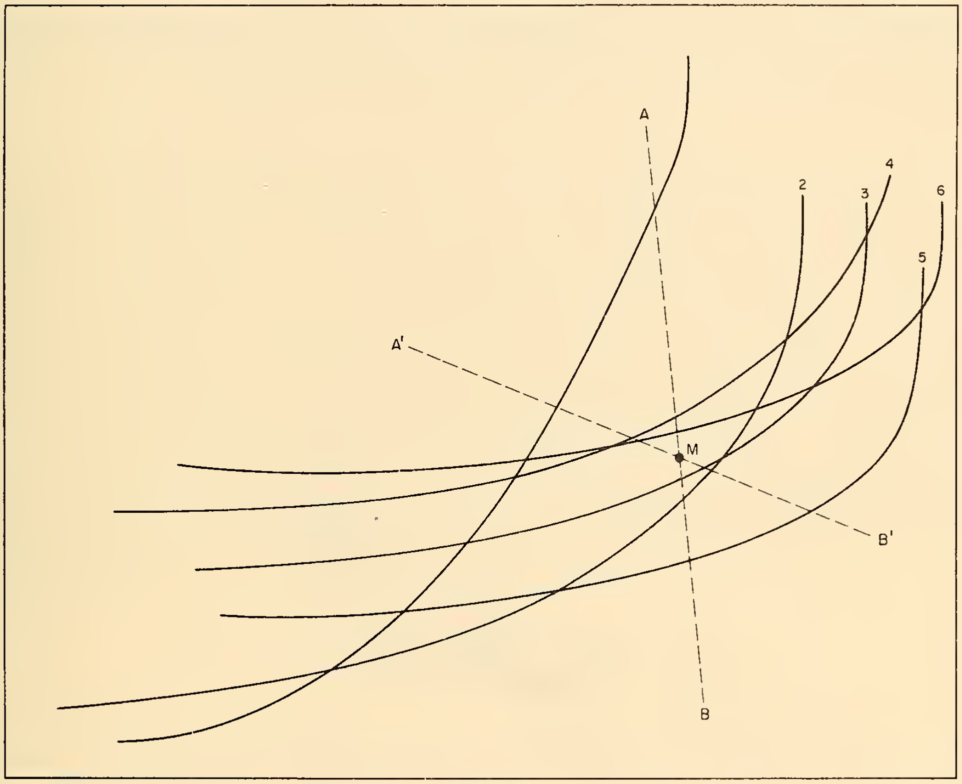


Figure 4

In this diagram, the curves 1, 2, 3 .... 6 represent parts of various virtual height curves. The point M represents a point on the median curve, which is to be found. What we wish to show is that for any line, AB, which passes through M and which crosses each of the curves 1, 2, 3, ... 6 once and only once, M is the median of the points of intersection of A B with these curves. This is obvious from figure 4. It is clear that the angle A B makes with the horizontal is unimportant (compare A' B'). It is not even necessary that the line A B be straight, provided it crosses each virtual height curve once and only once.

Therefore, various points, M, on the median curve can be found by first drawing a number of lines A B through the composite virtual height curves. Then, knowing the number of virtual height curves in the composite (the "median count"), one can count the intersection points from either side along the lines, A B, until the middle number of the count is reached. For an even count, the median is half-way between the points of the two middle values. This process is illustrated for a simple case of median count 6 in figure 5.

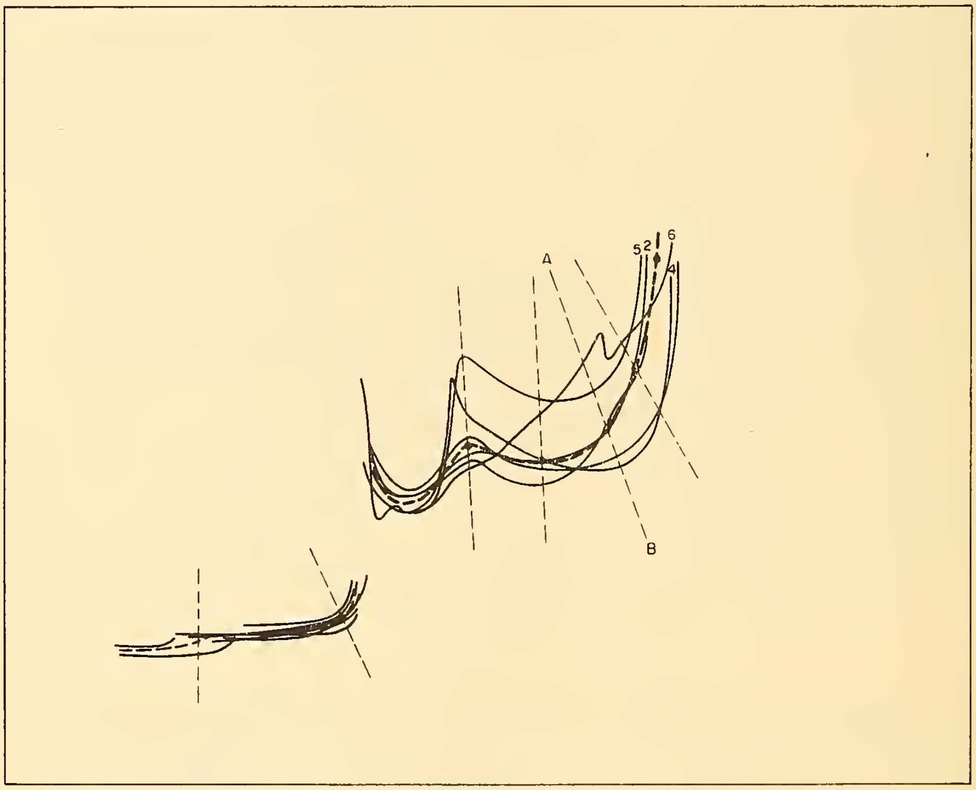


Figure 5

Dots in this figure show points on the median curve found by counting to midway between the 3rd and 4th intersection of the lines A B. Where the curves are so closely packed as to make counting impossible, the median may easily be drawn through the middle of

the pack, without counting. Account of the number of curves traced is kept in a block in the lower right corner of the form. It will frequently be necessary to count the number of intersection points when partial h'(f) curves have been traced. Not very many lines, A B, are necessary to define the general course of the median curve. These lines should be placed wisely, to identify important features of the majority of individual curves. It is important that each of the lines, A B, cross each of the virtual height curves once and only once.

A median curve may then be drawn through the M-points. The final median virtual height curve should resemble the majority of individual curves. For example, the highest F2 virtual height should be about as great as the average height of this point on the individual curves. If there is an F1 cusp on most of the curves, give the median curve an approximately average shape and height at this cusp. Make the foE cusp (if any) and the surrounding virtual heights of about average shape and height. Always use the local count (the number of intersection points) if this is less than the total number of curves traced.

VI. Treatment of Sporadic E Echoes

Es echoes are not used for analysis of N(h) profiles. If c, h, q, l, f types (see IGY Annals, Vol. III, Pt. 1, Wright, Knecht, Davies, 1957) of Es are present, they should be ignored. Only what can be seen of the ordinary-ray reflections from the E, F1, and F2 layers, complete with any stratifications which may be present, should be traced. In the Arctic, or during auroral or disturbed conditions, if a nighttime E layer is visible, its ordinary-ray should be included in the composite tracings. This applies also to some "retardation Es" echoes which are clearly observed to retard the F region echo. Account should be kept of the number of blanketing Es echoes (occulting any large portion of the F region echoes) in a space at the left end of the form.

VII. Oblique Echoes

Always attempt to identify the "overhead" echo. This will usually be the lowest ordinary-ray echo at each frequency, or the echo with the most nearly correct multiple echo. If the overhead echo cannot be identified throughout the frequency range, one may leave out the mysterious parts, and trace the reliable parts.

VIII. Spread Echoes

Trace any well-defined ordinary-ray echo which shows through the spread echo, and which, by continuity with surrounding ionograms, seems to be representative of the general critical-frequency variation. In severe cases of spread echo, either or both the inner and outer limits of the spread may be traced, <u>if they are well defined</u>. In counting the median, <u>each</u> traced curve must counted; thus the final count can exceed the number of days in the month, if spread echo is observed. Account should be kept of the number of "spread" ionograms in the space F at the left end of the form.

IX. The Extraordinary-Ray

The extraordinary-ray should not be confused with the ordinary-ray. The only part of the extraordinary-ray required at present on the composite tracings is any observable portion of the X-ray rising to the gyro-frequency at night. See figure 6.

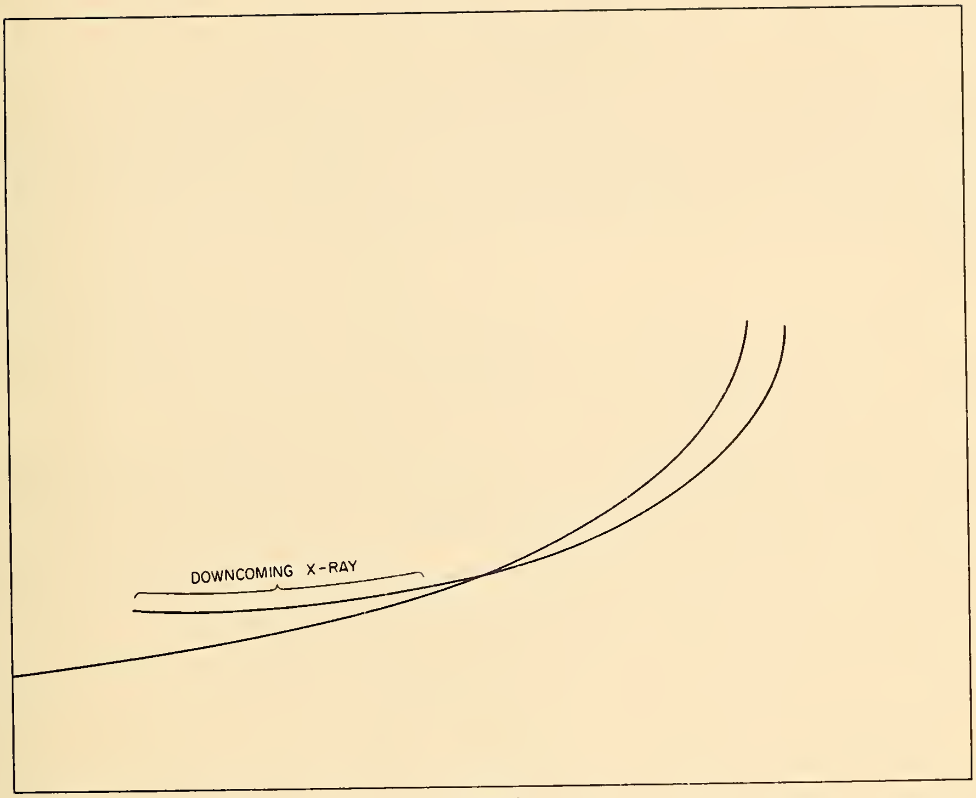


Figure 6

Only the downcoming portion of the X-ray is required. It is advisable to trace this in a contrasting color (blue) to avoid confusion with the composite ordinary-ray traces.

X. Scaling the Median Virtual Height Curve

It is now assumed that a satisfactory median virtual height curve has been obtained by the methods outlined above. This median curve should be drawn carefully with a hard red pencil.

Now, ignoring the surrounding maze of individual curves, enough virtual heights are to be scaled from the median curve so as to represent it numerically in some detail. Note that the frequency scale of the tracing is divided in equal intervals of log f. A numerical

log f scale is found across the top of the graph. Blocks at the bottom of the paper provide spaces for each of the log f lines in the graph immediately above. The first space in each block (with an alphabetic letter) corresponds to the left-hand heavy log f line immediately above. These heavy log f lines are at intervals of 0.1 log f.

The virtual height at each point where the median curve crosses a 0.1 log f line is to be scaled to the nearest kilometer and written beside the letter in the corresponding space below. Next, virtual heights should be scaled at as many 0.01 log f lines as necessary to describe fairly completely the variation in the virtual height curve within each 0.1 log f interval. It is not necessary to scale every 0.01 log f value. The examples shown in figure 3 should give an idea of the amount of extra points required.

To decide how many 0.01 log f values are needed in a given interval, try to imagine a straight line connecting any two consecutive scaled points. This is roughly how the computer "sees" the numerical data. Add extra scaled values wherever the real curve "bends" away from the imagined straight line by more than about two millimeters (or about the distance of 10 km on the tracing form).

Each value of virtual height should be scaled to the nearest kilometer. The heights should be written into the appropriate box beside the number telling at which 0.01 log f line it was scaled. Simply leave unused boxes blank. The computer finds the proper frequency to associate with each height by the position in the tabulation of each value, so it is very important to put the heights in the correct box.

XI. Scaling foF2

The median value of foF2 should be scaled from the median virtual height curve. Instead of scaling foF2 in Mc/s, it is more accurate to scale log foF2 in units of 0.001 log f from the scale at the top of the graph. It should be written in the space provided at the right-hand end of the form.

XII. Use of Standard Scaling Letters

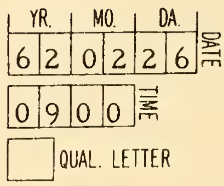
Spaces have been provided at the left end of the form for those letters which describe conditions of special interest to this method of analysis. The special cases for Spread Echo and for blanketing Es have already been noted. Other spaces are provided for noise (S), loss of observations (C), or blanketing Sporadic E (B). Account should be kept in these spaces of the number of ionograms affected by these causes. At the end of the month a single letter may be entered in the space provided beside the time box (see below). A letter should only be added if it occurs in more than 1/2 the count.

XIII. Recording the Date and Time

The name of the ionosphere station, its standard time zone, the month and whole-hour are to be written in the appropriate spaces at the top of each of the 24 forms used for a month's composite virtual height curves. Numbers designating the year, month and whole-hour of the tracings should also be written in the small boxes provided for the convenience of the punched-card machine operators.

The spaces for "Day" are to be filled in with the total number of day's tracings which appear on the forms.* As remarked earlier, a small tally written in the appropriate box on the form, to which one mark is added as each tracing is made, will help to keep account of the number of tracings; it should be kept in the space provided. Thus ~~IIII~~ III represents an accumulated tally of 8 tracings.

The minutes-blocks beside "Time" should be filled in with zeros.* Therefore, the completed Date-Time blocks for the month of February 1962 at 0900 containing a total of 26 tracings would look like this:



IV. Mailing Address

Scaled median virtual height data and composite tracings should be sent on a monthly basis to

National Bureau of Standards
Central Radio Propagation Laboratory
82.70 Vertical Soundings Research Section
Boulder, Colorado, U.S.A.

from those stations participating in the "Composite Virtual Height" program of the National Bureau of Standards.

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* Spaces for "Day" and "Minutes" are shown on these forms to permit their use in other specialized programs.

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King, G. A. M. "A convenient method of getting representative Ionospheric heights" J. Geophys. Research, 65, 1623-1624 (1960).

Schmerling, E. R. and J. O. Thomas "The distribution of electrons in the undisturbed F2 layer of the Ionosphere", Phil. Trans. Roy. Soc. Series A, 248, 609-620 (1956).

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U. S. DEPARTMENT OF COMMERCE
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